# Effects of Fall and Spring Seeding Date and Other Agronomic Factors on Infestations of Root Maggots, *Delia* spp. (Diptera: Anthomyiidae), in Canola

L. M. DOSDALL,[1] G. W. CLAYTON,[2] K. N. HARKER,[2], J. T. O'DONOVAN,[3] AND F. C. STEVENSON[4]

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**ABSTRACT** Several agronomic benefits can result from fall seeding of canola (*Brassica* spp.), but extensive research data are lacking on the potential impact of this practice on infestations of root maggots (*Delia* spp.) (Diptera: Anthomyiidae), which are major pests of the crop in western Canada. Field experiments making up 13 location by year combinations were conducted in central Alberta, Canada, from 1998 to 2001 to determine the effect of fall versus spring seeding of canola on root maggot damage. Depending on the experiment, interactions with seeding rate, seed treatment, timing of weed removal, and canola species (cultivar) also were investigated. Root maggot damage declined with an increase in seeding rate for plots seeded in May but not in fall or April. Susceptibility to infestation was greater for plants of *Brassica rapa* L. than *Brassica napus* L., but seed treatment had no effect on damage by these pests. Combined analysis using data from all experiment by location by year combinations indicated that seeding date had no significant effect on root maggot damage. The extended emergence of *Delia* spp. adults, which spans the appearance of crop stages vulnerable to oviposition regardless of seeding date, prevented reduced root maggot attack. Covariance analysis demonstrated the importance of increasing seeding rate for reducing root maggot infestations, a practice that can be especially beneficial for May-seeded canola when growing conditions limit the ability of plants to compensate for root maggot damage. Results determined with the small plot studies described here should be validated in larger plots or on a commercial field scale, but both the combined and covariance analyses indicate that seeding canola in fall does not predispose plants to greater damage by larval root maggots than seeding in spring.

**KEY WORDS** *Delia* spp., root maggots, canola, fall seeding, plant density

The cabbage maggot, *Delia radicum* (L.), and the turnip maggot, *Delia floralis* (Fallén) (Diptera: Anthomyiidae), are chronic pests in the production of canola (*Brassica* spp.) in western Canada, especially in central Alberta, where yield losses from root maggots can reach 50% in crops of *Brassica rapa* L. and 18% in *Brassica napus* L. (Griffiths 1986a,b, 1991; Soroka et al. 2004). Root maggots overwinter as puparia beneath the soil surface. Adults emerge from mid-May to mid-July (Dosdall et al. 1996b), and after emerging they disperse to locate suitable host plants for mating and reproduction. Adults disperse at rates ranging from ≈8 to 20 m/d (Hawkes 1972). Cabbage maggot females make several short, spiral flights before ovipositing on a suitable host plant (Kostal and Finch 1994). Most oviposition on canola occurs in mid- to late June when plants are in the rosette and bud stages (Griffiths 1986a, Dosdall et al. 1994). Root maggot larvae feed on the conductive and storage cells of the taproot phloem, periderm, and xylem parenchyma, disrupting the transport of water and nutrients between the root and upper regions of the plant (McDonald and Sears 1992). Infestations can be associated with leaf and stem wilting, poor seed set, and in severe infestations, plant mortality with roots completely severed (Griffiths 1986a, McDonald and Sears 1992).

In the short growing season of the Northern Great Plains of North America, fall dormant seeding of canola has recently attracted considerable interest among canola producers. Seeding canola in fall, rather than at more traditional times in mid-May, can advance crop development resulting in early maturity and reduced risk of preharvest frost damage and grade loss (Kirkland and Johnson 2000, Clayton et al. 2004a). In fall-seeded systems, yields and seed oil concentrations were shown to increase by ≈40 and 5%, respectively, due to enhanced use of early season soil moisture, and the timing of flowering and seed maturation during cooler and moister periods of the growing season (Kirkland and Johnson 2000, Johnston et al. 2002).

[1] Department of Agricultural, Food and Nutritional Science, 4-10 Agriculture/Forestry Centre, University of Alberta, Edmonton, AB, Canada T6G 2P5.

[2] Agriculture and Agri-Food Canada, Lacombe Research Centre, 6000 C&E Trail, Lacombe, AB, Canada T4L 1W1.

[3] Agriculture and Agri-Food Canada, Beaverlodge Research Farm, Box 29, Beaverlodge, AB, Canada T0H 0C0.

[4] 142 Rogers Rd., Saskatoon, SK, Canada S7N 3T6.

**Table 1. Study locations, years of study, and factors varied for experiments investigating fall versus spring seeding effects on root maggot infestations in canola**

| Exp | Location, yr | Factors investigated |
|---|---|---|
| 1. Seeding date–seeding rate–seed treatment–canola species | Vegreville, 1998–1999 and 1999–2000 | Seeding date (early fall, late fall, early spring, normal spring) |
| | Fort Saskatchewan, 1998–1999 and 1999–2000 | Seeding rate (7.5, 10.0, and 12.5 kg/ha) |
| | | Seed treatment (Extender, Vitavax Single, Vitavax rs) |
| | | Canola species (*B. napus*, *B. rapa*) |
| 2. Seeding date–time of weed removal–canola cultivar | Lacombe, 1998–1999 and 1999–2000 | Seeding date (late fall, early spring, normal spring) |
| | Beaverlodge, 1999–2000 | Timing of weed removal (two-, four-, six-leaf stages) |
| | | *B. napus* cultivar (Exceed, InVigor 2153) |
| 3. Seeding date–seed -treatment-canola cultivar | Lacombe, 1998–1999, 1999–2000, and 2000–2001 | Seeding date (early fall, late fall, early spring, normal spring) |
| | Beaverlodge, 1998–1999, 1999–2000, and 2000–2001 | Seed treatment (Extender or no coating) |
| | | *B. napus* cultivar (InVigor 2153, Exceed, LG 3235, 45A71) |

Increased equipment and labor efficiencies, as a result of spreading out seeding dates of canola relative to other crops, are an added benefit to producers (Clayton et al. 2004a).

However, benefits from fall dormant seeding of canola have not always been realized. Karamonas et al. (2002) reported yields that were 4–31% less in fall- than in spring-seeded canola, and Clayton et al. (2004a) found that 46% lower plant densities associated with fall-seeded canola resulted in substantially reduced yields compared with canola seeded in spring. Reduced yields in fall-seeded systems have most frequently been attributed to difficulties with plant stand establishment because of premature seed germination when warm, moist conditions occur late in the season after fall seeding has been completed. Polymer seed coatings have recently been developed that prevent fall germination by impeding the imbibition rate of water in seeds when atypical warm fall environmental conditions occur (Chachalis and Smith 2001). A polymer seed coating has been developed for canola under the trade name Extender (Zaychuk and Enders 2001), and it was found to improve seedling density and seed yield when soil temperatures after fall seeding were above 5°C (Clayton et al. 2004b, Johnson et al. 2004).

Canola plants with large basal stem diameters are more susceptible to root maggot oviposition and damage than plants with smaller stems (Dosdall et al. 1995, 1996a), a condition that would occur earlier in the season in fall- than spring-seeded crops because of their earlier germination and development. Shifting the timing of greatest susceptibility to root maggot attack could then alter overall crop damage and yield loss; yet, the effects of fall versus spring seeding of canola on feeding damage by root maggots have not been investigated previously. This study was undertaken to investigate the impact of seeding in fall (October–November) compared with spring (April–May), on feeding damage by root maggots. Interactions with additional agronomic factors including seeding rate, canola species and cultivar, time of weed removal, and seed coating also were assessed to determine their impact on root maggot infestations under fall and spring seeding conditions.

## Materials and Methods

**Study Sites and Experimental Designs.** The studies were conducted at Vegreville (112° 03′ W, 53° 30′ N), Fort Saskatchewan (113° 13′ W, 53° 43′ N), Lacombe (113° 44′ W, 52° 28′ N), and Beaverlodge, Alberta (119° 26′ W, 55° 13′ N) from 1998 through 2000. Soil type at Vegreville was Black Chernozemic loam (35% sand, 34% silt, and 31% clay), with pH 6.3 and 7.2% organic matter; at Fort Saskatchewan, soil type was also Black Chernozemic loam (33% sand, 39% silt, and 28% clay), with pH 6.1 and 7.4% organic matter. Soil type at Lacombe was Black Chernozemic clay loam (43% sand, 21% silt, and 36% clay) with a pH of 5.9 and 8.2% organic matter content, and at Beaverlodge soil type was Mollic Gray Luvisol clay loam (31% sand, 44% silt, and 26% clay) with pH 5.8 and 5.9% organic matter.

Each of three field experiments included a common treatment in which canola was seeded in both fall and the following spring. Each experiment also included factorial combinations of fall and spring seeding and one or more additional agronomic factors randomized in complete blocks with four replications. The factors, study locations, and years of study for each of the experiments are summarized in Table 1. In total, 13 sites (location by year combinations) of data were accumulated to assess the effects of fall versus spring seeding on root maggot infestations.

For each of the experiments, fertilizer was applied to the plots at the time of seeding according to the soil test recommendations for canola production. Rainfall was monitored at each site during the period from seeding to harvest by using tipping bucket rain gauges. Plots were hand weeded in experiment 1, but weed control in the other experiments was achieved by herbicide applications. In-crop herbicides were ap-

**Table 2. Calendar of seeding operations at the study sites in Alberta, Canada**

| Location, yr | Early fall | Late fall | Early spring | Normal spring |
|---|---|---|---|---|
| | | Exp 1: Seeding date–seeding rate–seed treatment–canola species | | |
| Vegreville | | | | |
| 1998–1999 | 14 Oct. 1998 | 31 Oct. 1998 | 29 April 1999 | 18 May 1999 |
| 1999–2000 | 27 Oct. 1999 | 8 Nov. 1999 | 25 April 2000 | 18 May 2000 |
| Fort Saskatchewan | | | | |
| 1998–1999 | 14 Oct. 1998 | 27 Oct. 1998 | 29 April 1999 | 17 May 1999 |
| 1999–2000 | 22 Oct. 1999 | 8 Nov. 1999 | 25 April 2000 | 16 May 2000 |
| | | Exp 2: Seeding date–time of weed removal–canola cultivar | | |
| Lacombe | | | | |
| 1998–1999 | | 5 Nov. 1998 | 29 April 1999 | 13 May 1999 |
| 1999–2000 | | 27 Oct. 1999 | 26 April 2000 | 15 May 2000 |
| Beaverlodge | | | | |
| 1999–2000 | | 25 Oct. 1999 | 19 April 2000 | 8 May 2000 |
| | | Exp 3: Seeding date–seed treatment–canola cultivar | | |
| Lacombe | | | | |
| 1998–1999 | 8 Oct. 1998 | 5 Nov. 1998 | 29 April 1999 | 13 May 1999 |
| 1999–2000 | 13 Oct. 1999 | 27 Oct. 1999 | 26 April 2000 | 15 May 2000 |
| 2000–2001 | 19 Oct. 2000 | 25 Oct. 2000 | 24 April 2001 | 15 May 2001 |
| Beaverlodge | | | | |
| 1998–1999 | 19 Oct. 1998 | 26 Oct. 1998 | 3 May 1999 | 11 May1999 |
| 1999–2000 | 12 Oct. 1999 | 25 Oct. 1999 | 19 April 2000 | 8 May 2000 |
| 2000–2001 | 18 Oct. 2000 | 26 Oct. 2000 | 25 April 2001 | 3 May 2001 |

plied at the recommended label rates to the different canola cultivars according to their herbicide tolerances as follows: glufosinate ammonium (Liberty, Bayer CropScience, Toronto, Ontario, Canada) at 500 g ([AI])/ha, glyphosate (Roundup, Monsanto, Winnipeg, Manitoba, Canada) at 450 g ([AI])/ha, and imazamox/imazethapyr (Odyssey, BASF, Florham Park, NJ) at 30 g ([AI])/ha. Merge, a surfactant-solvent (BASF Canada, Toronto, Ontario, Canada), was added to the imazamox/imazethapyr spray solution at 1% (vol:vol). All in-crop herbicides were applied in 100–110 liters of water per ha with flat fan nozzles at a pressure of 207–275 kPa.

**Experiment 1: Seeding Date–Seeding Rate–Seed Treatment–Canola Species.** Experiment 1 was conducted at Vegreville and Fort Saskatchewan in 1998–1999 and 1999–2000. The design included factorial combinations of seeding date (described below), seeding rate (7.5, 10.0, and 12.5 kg/ha), seed treatment (described below), and canola species (*B. rapa* 'Reward' and *B. napus* 'Q2'). Each treatment plot measured 6 by 2 m and encompassed eight rows spaced 20 cm apart.

A coulter double disc no-till drill was used to seed plots into wheat stubble on four dates, two in fall and two in spring (Table 2). Fall seeding dates were timed to coincide with the occurrence of soil temperatures of 0–5°C in the upper 2 cm of the soil profile ("early fall"), and temperatures of ≤0°C in the upper 5 cm of the soil profile ("late fall"). "Early spring" seeding occurred in late April after soil thawed and dried sufficiently to allow equipment access, and ≈10–14 d later when most farmers in the ecoregion were seeding canola ("normal spring").

Seed treatment formulations included coating with the fungicide carboxin (Vitavax Single, Gustafson, Plano, TX) at 22.5 ml/kg, coating with the fungicides carboxin and thiram plus the insecticide lindane at 1:2:15 g (AI) (Vitavax rs, 22.5 ml/kg, Gustafson), and coating with a synthetic polymer (Extender, Grow Tec, Edmonton, Alberta, Canada) designed to inhibit germination until after a period of frost (Zaychuk and Enders 2001).

**Experiment 2: Seeding Date–Time of Weed Removal–Canola Cultivar.** Experiment 2 was conducted at Lacombe in 1998–1999 and 1999–2000 and at Beaverlodge in 1999–2000. The study investigated factorial combinations of seeding date, time of weed removal, and canola cultivar. Treatment plots measured four by 12 m, and comprised 12 rows spaced 30 cm apart. Plots were seeded with a ConservaPak drill (ConservaPak Seeding Systems, Indian Head, Saskatchewan, Canada) at a rate of 8–9 kg/ha. All seed was treated with the fungicides carboxin and thiram plus the insecticide lindane at 1:2:15 g (AI) (Vitavax rs, 22.5 ml/kg, Gustafson), to reduce seedling mortality from phytopathogens and herbivory by flea beetles. To simulate uniform monocot weed populations, oats, *Avena sativa* L. 'Jasper') were seeded perpendicular to the canola rows with a press drill at a target density of 100 plants per m$^2$.

Seeding was performed on one date in late fall, after ground was frozen to an approximate depth of 5 cm, and on two dates in spring: early spring after the threat of nighttime frost seemed minor and soil had dried sufficiently to allow for access of seeding equipment, and normal spring when most growers in the region were seeding crops (Table 2). The glufosinate-tolerant cultivars of *B. napus* evaluated included the hybrid 'InVigor 2153' and the open-pollinated 'Exceed'. Weed control was achieved with ammonium glufosinate (Liberty, Bayer CropScience, Toronto, Ontario, Canada) at 500 g ([AI]) /ha applied as closely as possible to the two-, four-, and six-leaf stages of canola development. The herbicide was applied using a sprayer equipped with flat fan nozzles in 110 liters of water per ha at 275 kPa.

**Experiment 3: Seeding Date–Seed Treatment–Canola Cultivar.** Experiment 3 was conducted at Lacombe and Beaverlodge in 1998–1999, 1999–2000, and 2000–2001 and investigated factorial combinations of seeding date, canola cultivar, and seed treatment. Canola was direct-seeded into cereal stubble at a rate of ≈6 kg/ha at all site years with a ConservaPak air seeder equipped with narrow knife openers spaced 30 cm apart. Seeding dates comprised two dates in fall and two in spring by using a protocol similar to that described for experiment 1. The canola cultivars evaluated included the hybrid glufosinate-resistant InVigor 2153, the open-pollinated glufosinate-resistant Exceed, the glyphosate-resistant 'DK 3235', and the imazethapyr-resistant '45A71'. All seed was coated with the fungicides carboxin and thiram plus the insecticide lindane at 1:2:15 g (AI) (Vitavax rs, 22.5 ml/kg, Gustafson) to minimize seedling diseases and damage from flea beetle feeding. Fall-seeded plots were subjected to an additional seed coating with polymer (Extender, Grow Tec), to impede water imbibition by seeds and limit germination until the following spring. Treatment plots measured 3.6 by 15 m at Lacombe and 3.6 by 20 m at Beaverlodge.

**Assessments of Root Maggot Infestations and Canola Yield.** Root maggot infestation levels were assessed using damage ratings to canola taproots at the end of the season. At harvest, a sample of 25 canola roots was collected randomly from the two middle rows of each plot. The roots were bagged and labeled, and returned to the laboratory where they were washed and scored for degree of root maggot damage by using the semi-quantitative rating scale of Dosdall et al. (1994) where 0 represents no root damage, 1 represents <10% of the root surface with root maggot feeding channels, 2 represents 11–25%, 3 represents 26–50%, 4 represents 51–75%, and 5 represents 76–100% of the taproot surface area damaged.

**Data Analyses.** The analysis was conducted separately for each experiment and across all experiments (combined analysis) with the PROC GLIMMIX procedure of SAS (SAS Institute, Cary, NC; http://support.sas.com/rnd/app/papers/glimmix.pdf; Littel et al. 1996), with blocks and sites (experiment by location by year combinations) as random effects and treatments as fixed effects. At select sites, a right-tail skewed data distribution occurred. A Poisson distribution and log link function model specifications was used for these sites with nonnormal data distributions. For the other site with normal data distribution, a Gaussian distribution and identity link function model specific was used. A combination of variance estimates, and *P* values were used to determine the importance of site by treatment interactions. Contrasts were used to make specific comparisons among treatment combination levels. Treatment effects were considered significant at $P < 0.05$.

A second analysis was conducted for the combined data set (all experiments) to examine the relationship between seeding date, root maggot damage, and canola plant density or seed yield. The aim of the analysis was to determine whether variations in plant density influenced seeding date effects on root maggot damage. Data were normally distributed when combined; therefore, data were analyzed with the PROC MIXED procedure of SAS (Littel et al. 1996) with blocks and experiment by site (location by year) combinations as random effects and seeding date as a fixed effect. The covariables, plant density or seed yield, were included separately as a factor cross-classified with seeding date, and root maggot damage as the response variable. A significant ($P < 0.05$) interaction between the covariable and seeding date indicated those instances where the covariable affected root maggot damage differences among seeding dates. Where a significant interaction occurred, an analysis with the covariable nested within each seeding date was used to estimate the slope coefficients (i.e., the effect of covariable as a regressor) and its statistical significance for each seeding date. Effects and regression coefficients were considered significant at $P < 0.05$.

**Table 3. Precipitation (centimeters) received during the growing season at the study sites in Alberta, Canada, in comparison with long-term normal precipitation levels**

| Site | 1999 | 2000 | 2001 | Long-term avg[a] |
|---|---|---|---|---|
| Vegreville | 21.2 | 19.2 | | 24.1 |
| Fort Saskatchewan | 24.3 | 21.4 | | 27.7 |
| Lacombe | 42.3 | 31.0 | 31.8 | 31.8 |
| Beaverlodge | 15.7 | 31.0 | 24.3 | 28.2 |

[a] Long-term average precipitation = mean precipitation during 1907–1990 inclusive.

## Results

**Environmental Conditions and Plant Development.** Precipitation during the growing seasons approximated long-term average values for all site-years except during 1999 when rainfall exceeded the long-term average value at Lacombe by 10.5 cm and was 12.5 cm less than the long-term average at Beaverlodge (Table 3). Root maggot infestation levels are correlated with soil moisture content (Griffiths 1986b), and these quantities of precipitation were conducive to development of significant root maggot infestations. At all sites, residual soil moisture levels were sufficient to ensure uniform germination and emergence of canola seedlings.

Canola development was more advanced in fall-than in spring-seeded plots. For example, by early June in 1999 and 2000, fall-seeded canola at Vegreville and Fort Saskatchewan was in the three- to four true-leaf stages [growth stages 2.3–2.4 of Harper and Berkenkamp (1975)], but spring-planted canola was still in the cotyledon stage (growth stage 1.0). Canola seeded in fall reached 50% flowering ≈10 d earlier than plants seeded in April, and ≈20 d before plants seeded in May. Fall-seeded plants matured 5–21 d earlier than plants seeded in April and ≈10–30 d before plants seeded in May.

**Table 4. Analysis of variance for root damage from field experiments conducted in Vegreville and Fort Saskatchewan, Alberta, Canada, to investigate effects of canola seeding date (early fall, late fall, early spring, and late spring), species (*B. rapa* and *B. napus*), seeding rate (7.5, 10.0, and 12.5 kg/ha), and seed coating formulation (Vitavax Single, Vitavax rs, and Extender) on root maggot damage**

| Effect/contrast | Root damage *P* value | *F* value | Numerator df | Denominator df | Variance estimate[a] | Z value | % total variance[b] |
|---|---|---|---|---|---|---|---|
| Canola species (C) | 0.006** | 27.0 | 1 | 4 | . | | |
| Seeding date–seed coat (S) | 0.851 | 0.5 | 9 | 25 | | | |
| Fall (with Extender) vs. spring (S1) | 0.361 | 0.9 | 1 | 35 | | | |
| April vs. May (S2) | 0.192 | 1.8 | 1 | 41 | | | |
| April vs. May × seed coat (S3) | 0.431 | 0.6 | 1 | 20 | | | |
| C x S | 0.293 | 1.3 | 9 | 27 | | | |
| C × S1 | 0.238 | 1.4 | 1 | 70 | | | |
| C × S2 | 0.029* | 5.0 | 1 | 78 | | | |
| C × S3 | 0.250 | 1.4 | 1 | 17 | | | |
| Seeding rate (R) | < 0.001** | 15.9 | 2 | 721 | | | |
| C × R | 0.679 | 0.4 | 2 | 721 | | | |
| S × R | 0.670 | 0.8 | 18 | 721 | | | |
| C × D × R | 0.172 | 1.3 | 18 | 721 | | | |
| C × S1 × R[c] | 0.716 | 0.1 | 1 | 721 | | | |
| C × S2 × R | 0.967 | 0.0 | 1 | 721 | | | |
| C × S3 × R | 0.175 | 1.8 | 1 | 721 | | | |
| Site (T) | | | | | 0 | | 0 |
| T × C | | | | | 0.0262 | 1.27 | 52 |
| T × S | | | | | 0.0193** | 2.43 | 38 |
| T × C × S | | | | | 0.0049 | 1.35 | 10 |
| T × R | | | | | < 0.0001 | | 0 |
| T × C × R | | | | | 0 | | 0 |
| T × S × R | | | | | 0 | | 0 |
| T × C × S × R | | | | | 0 | | 0 |

[a] Statistical significance values of the root damage and variance components are *, $0.05 \geq P \geq 0.01$ and **, $P < 0.01$.
[b] Variance for a given effect, divided by the sum of the variance estimate for the four effects associated with site, and multiplied by 100.
[c] Comparison of 7.5 and 12.0 kg/ha seeding rates.

**Experiment 1: Seeding Date–Seeding Rate–Seed Treatment–Canola Species.** Root maggot damage in experiment 1 was not affected by seeding date (Table 4). However, highly significant effects were attributable to canola species ($F = 27.0$; df = 1, 4; $P = 0.006$) and seeding rate ($F = 15.9$; df = 2, 721; $P < 0.001$). Plants of *B. rapa* were more susceptible to root maggot damage than *B. napus*, with mean damage ratings of *B. rapa* plants for a given seeding date and seed treatment formulation often twice those of *B. napus* (Table 5). Root maggot damage declined with an increase in seeding rate: mean damage ratings were 1.06 (SE = 0.09), 1.03 (SE = 0.09), and 0.94 (SE = 0.09) for canola seeded at rates of 7.5, 10.0, and 12.5 kg/ha, respectively (least significant difference $[\mathrm{LSD}]_{0.05} = 0.04$). A significant interaction was observed between canola species and April versus May seeding ($F = 5.0$; df = 1, 78; $P = 0.029$; Table 4). This interaction was associated with greater damage to *B. rapa* than *B. napus* for April-seeded compared with May-seeded plants (Table 5). Seed coating formulation had no effect on root maggot damage, regardless of seeding date and the other factors ($F = 0.5$; df = 9, 25; $P > 0.05$) (Tables 4 and 5).

**Table 5. Mean root maggot damage ratings (SE) of plants of *B. rapa* and *B. napus* seeded in spring and the preceding fall, and subjected to different seed treatment formulations**

| Seeding date, seed treatment | *B. rapa* | *B. napus* |
|---|---|---|
| Early fall, Extender | 1.46 (0.15) | 0.65 (0.15) |
| Early fall, Vitavax | 1.38 (0.14) | 0.62 (0.14) |
| Early fall, Vitavax rs | 1.28 (0.14) | 0.59 (0.14) |
| Late fall, Extender | 1.36 (0.15) | 0.79 (0.15) |
| Late fall, Vitavax | 1.39 (0.14) | 0.73 (0.14) |
| Late fall, Vitavax rs | 1.33 (0.14) | 0.71 (0.14) |
| Early spring, Vitavax | 1.35 (0.14) | 0.61 (0.14) |
| Early spring, Vitavax rs | 1.22 (0.14) | 0.54 (0.14) |
| Normal spring, Vitavax | 1.23 (0.14) | 0.85 (0.14) |
| Normal spring, Vitavax rs | 1.31 (0.14) | 0.83 (0.14) |
| $\mathrm{LSD}_{0.05}$ | 0.28 | |

The seeding date–seed coat effect varied among sites ($Z = 2.43$, $P < 0.05$, and total site variation >25%) (Table 4). The site by canola species interaction was also noteworthy ($Z = 1.27$, $P = 0.10$, and total site variation >25%).

**Experiment 2: Seeding Date–Time of Weed Removal–Canola Cultivar.** Root maggot damage in experiment 2 was not affected significantly by seeding date ($F = 0.53$; df = 2, 4; $P = 0.626$), canola cultivar ($F = 8.56$; df = 1, 2; $P = 0.100$), or time of weed removal ($F = 1.29$; df = 2, 4; $P = 0.370$) (Table 6). A significant interaction was observed for cultivar by fall versus spring seeding by time of weed removal. This interaction corresponded with greater root maggot damage to Exceed plants seeded in spring with weed removal at the two- and four-leaf stages (mean damage 2.54 and 2.73, respectively; SE = 0.59), compared with InVigor 2153 plants seeded in fall with weed removal at the six-leaf stage (mean damage 2.19, SE = 0.59). Significant site by treatment interactions were not observed ($P > 0.05$ and total site variation >25%) (Table 6).

**Experiment 3: Seeding Date–Seed Treatment–Canola Cultivar.** Seeding date, seed treatment, and canola cultivar had no significant effects on root maggot damage ($P > 0.05$) (Table 7). Interactions between canola varieties and seeding date by seed treat-

**Table 6. Analysis of variance for root damage from field experiments conducted in Lacombe and Beaverlodge, Alberta, Canada, to investigate the effects of seeding date (late fall, early spring, and late spring), timing of weed removal (two-, four-, and six-leaf stages of canola development), and *B. napus* cultivar (Exceed and InVigor 2153) on root maggot damage**

| Effect/contrast | Root damage $P$ value | $F$ value | Numerator df | Denominator df | Variance estimate[a] | Z value | % total variance[b] |
|---|---|---|---|---|---|---|---|
| Canola cultivar (V) | 0.100 | 8.56 | 1 | 2 | | | |
| Seeding date (D) | 0.626 | 0.53 | 2 | 4 | | | |
| Fall vs spring (D1) | 0.417 | 0.82 | 1 | 4 | | | |
| Early spring vs normal spring (D2) | 0.651 | 0.24 | 1 | 4 | | | |
| V × D | 0.474 | 0.90 | 2 | 4 | | | |
| V × D1 | 0.275 | 1.59 | 1 | 4 | | | |
| V × D2 | 0.667 | 0.22 | 1 | 4 | | | |
| D × TWR | 0.165 | 2.15 | 4 | 8 | | | |
| V × D × TWR | 0.151 | 2.27 | 4 | 8 | | | |
| V × D1 × TWR[c] | 0.038* | 6.19 | 1 | 8 | | | |
| V × D2 × TWR | 0.228 | 1.71 | 1 | 8 | | | |
| Time of weed removal (TWR) | 0.370 | 1.29 | 2 | 4 | | | |
| V × TWR | 0.246 | 2.04 | 2 | 4 | | | |
| Site (T) | | | | | 0.979 | 0.98 | 96 |
| T × V | | | | | 0.005 | 0.35 | 1 |
| T × D | | | | | 0.011 | 0.59 | 1 |
| T × V × D | | | | | 0.010 | 0.56 | 1 |
| T × TWR | | | | | 0.007 | 0.82 | 1 |
| T × V × TWR | | | | | 0.001 | 0.15 | 0 |
| T × D × TWR | | | | | <0.001 | 0.05 | 0 |
| T × V × D × TWR | | | | | 0.004 | 0.39 | 0 |

[a] Statistical significance values of the root damage and variance components are *, $0.05 \geq P \geq 0.01$ and **, $P < 0.01$.
[b] Variance for a given effect, divided by the sum of the variance estimate for the four effects associated with site, and multiplied by 100.
[c] Comparison of weed removal at the two- and four-leaf stages of canola development vs the six-leaf stage.

ment were not significant ($P > 0.05$); however, a marginally significant interaction was observed for InVigor 2153 at the fall versus spring seeding date ($F = 3.61$; df = 1, 33; $P = 0.07$) (Table 7). A significant site by seeding date by seed treatment interaction occurred ($Z = 2.04$, $P = 0.031$), although the total site variation explained by this interaction was of questionable importance (<5%) (Table 7).

When root maggot damage data were averaged across all three experiments, seeding date had no significant effect on root maggot damage ($P = 0.25$). Mean root damage ratings were 2.14 (SE = 0.35), 2.02 (SE = 0.35), and 2.10 (SE = 0.35) for *B. napus* seeded in late fall, early spring, and normal spring, respectively ($LSD_{0.05} = 0.15$). Variance estimates indicated that effects of site and site by seeding date were significant ($P < 0.05$); however, the total variance associated with the site by seeding date interaction was only 1%.

Covariance analysis indicated that at plant densities approximating those achieved with fall seeding

**Table 7. Analysis of variance for root damage from field experiments conducted in Lacombe and Beaverlodge, Alberta, Canada to investigate the effects of seeding date (early fall, late fall, early spring, and late spring), seed treatment formulation (Extender and no treatment), and *B. napus* cultivar (Exceed, InVigor 2153, DK 3235, and 45A71) on root maggot damage**

| Effect/contrast | Root damage $P$ value | $F$ value | Numerator df | Denominator df | Variance estimate[a] | Z value | % total variance[b] |
|---|---|---|---|---|---|---|---|
| Canola cultivar (V) | 0.534 | 0.81 | 3 | 6 | | | |
| Seeding date–seed treatment (S) | 0.796 | 0.46 | 5 | 14 | | | |
| Fall with Extender vs. spring (S1) | 0.293 | 1.19 | 1 | 14 | | | |
| Early spring vs. late spring (S2) | 0.649 | 0.22 | 1 | 14 | | | |
| V x S | 0.121 | 1.61 | 15 | 35 | | | |
| 45A71: S1[c] | 0.554 | 0.36 | 1 | 33 | | | |
| 45A71: S2 | 0.254 | 1.35 | 1 | 33 | | | |
| DK3235: S1 | 0.151 | 2.16 | 1 | 33 | | | |
| DK3235: S2 | 0.960 | <0.01 | 1 | 33 | | | |
| Exceed: S1 | 0.561 | 0.34 | 1 | 33 | | | |
| Exceed: S2 | 0.942 | 0.01 | 1 | 33 | | | |
| InVigor 2153: S1 | 0.066 | 3.61 | 1 | 33 | | | |
| InVigor 2153: S2 | 0.798 | 0.07 | 1 | 33 | | | |
| Site (T) | | | | | 0.698 | 1.37 | 93 |
| T × V | | | | | 0.015 | 1.02 | 2 |
| T × S | | | | | 0.031* | 2.04 | 4 |
| T × V × S | | | | | 0.009 | 1.00 | 1 |

[a] Statistical significance values of the root damage and variance components are *, $0.05 \geq P \geq 0.01$ and **, $P < 0.01$.
[b] Variance for a given effect, divided by the sum of the variance estimate for the four effects associated with site, and multiplied by 100.
[c] Seeding date by seed treatment comparisons for each cultivar.

**Table 8. Summary of the regression (covariance analysis of variance) of root maggot damage to canola taproots vs plant density (covariable) for plots seeded in fall (October–November), April, and May at various sites in central Alberta, Canada, from 1998 to 2001**

| Seeding date | Plant density mean[a] | Slope[b] | | |
|---|---|---|---|---|
| | | Coefficient | SE | *P* value |
| Fall | 50 | −0.00136 | 0.00267 | 0.615 |
| April | 83 | 0.00010 | 0.00232 | 0.966 |
| May | 79 | −0.00616 | 0.00242 | 0.014 |

[a] $LSD_{0.05} = 9$, derived from univariate analysis of variance for plant density.
[b] *P* value derived from covariance ANOVA for the regression of damage versus plant density.

(mean 50 plants per $m^2$), root maggot damage was significantly greater for May- and fall-seeded plots than for April (Table 8; Fig. 1); a significant difference was observed for May versus April seeding ($t = -2.64$; df = 1, 20; $P = 0.016$), but not for May versus fall seeding ($t = 1.33$; df = 1, 28; $P > 0.05$). At plant densities near the mean of all seeding dates (72 plants per $m^2$), and at densities approximating the mean of those achieved for spring seeding (82 plants per $m^2$), root damage was similar among dates ($P > 0.05$). However, at higher densities of 120 plants per $m^2$, root damage was nearly greater for April than May ($t = 1.66$; df = 1, 21; $P = 0.113$), but the difference for fall compared with April was not important ($t = -1.26$; df = 1, 24; $P = 0.219$). A significant and negative slope coefficient occurred for the May seeding date ($-0.00616$; $t = -2.54$; df = 1, 54; $P = 0.014$), whereas the slope coefficients for April (0.00010, $P > 0.05$) and fall ($-0.00136$; $t = -0.51$; df = 1, 45; $P > 0.05$) did not indicate significant trends (Table 8; Fig. 1). Canola seed yield did not affect root maggot damage responses among seeding dates ($F = 2.11$; df = 2, 24; $P > 0.05$).

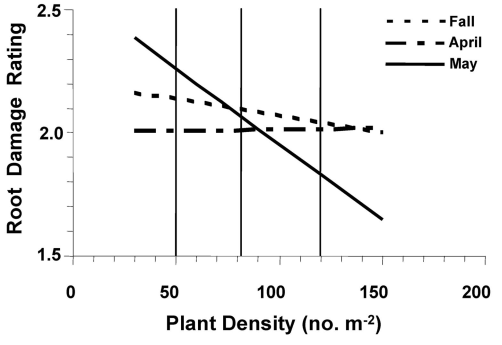


Fig. 1. Predicted trends for the regression of root maggot damage to canola taproots versus plant density (covariable) for plots seeded in fall (October–November), April, and May at various sites in central Alberta, Canada, from 1998 to 2001. Vertical lines projecting from the x-axis indicate mean density for fall (50 plants per $m^2$) and spring (82 plants per $m^2$) seeding. A vertical line projecting optimal (target) plant density (120 plants per $m^2$) also is shown.

## Discussion

Manipulating seeding date to produce asynchrony between the vulnerable stage of crop plants and the abundance of herbivores can be a sustainable strategy for managing insect pest infestations, and there are many instances where this strategy has been effective in various cropping systems. For example, altering planting date can reduce economic damage from Hessian fly, *Mayetiola destructor* (Say), in winter wheat (*Triticum* spp.) (Teetes 1991); sorghum midge, *Contarinia sorghicola* (Coquillett), in sorghum, *Sorghum bicolor* (L.) Moench. (Wiseman and McMillan 1967); Japanese beetle, *Popilla japonica* Newman, in corn, *Zea mays* L. (Woodside 1954); and boll weevil, *Anthonomus grandis grandis* Boheman, in cotton (*Gossypium* spp.) (Showler et al. 2005).

In the Northern Great Plains of North America, dormant-seeding canola in fall has considerable potential for influencing insect pest infestations because this practice is associated with substantial alterations in the timing of crop phenological events compared with seeding in spring. For example, canola seeded in fall in the ecoregions encompassed by our studies flowered as much as 16–20 d earlier than plants seeded in spring, and it matured as much as 30 d before spring-seeded plants (Clayton et al. 2004a, Dosdall and Stevenson 2005, O'Donovan et al. 2005). Dosdall and Stevenson (2005) found that fall seeding of canola had dramatic effects on infestations of flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae), the major pests of crop seedlings in western Canada. Seeding in fall enabled plants to progress beyond the vulnerable cotyledon stage by the time that most flea beetle invasion and damage occurred, indicating that canola could be grown in fall-seeded systems with considerably less insecticide than is currently used.

Most *Delia* spp. oviposition occurs when canola is in the rosette to bud stages of development [growth stages 2.2–3.1 of Harper and Berkenkamp (1975)], and few eggs are deposited on plants in flower or later (Griffiths 1986a, Dosdall et al. 1994). In spring-seeded canola, rosette to bud development and peak oviposition by *Delia* spp. generally occur from mid- to late June, but seeding in fall advanced crop development so that the vulnerable stages for oviposition occurred from late May to mid-June. However, this did not lessen root maggot infestation levels and damage. In western Canada, both *D. radicum* and *D. floralis* have an adult emergence period extending from mid-May to mid-July (Dosdall et al. 1996b), an adaptation that enables them to use host plants with a broad range of seeding dates. In spring-seeded crops, females that emerge before canola is vulnerable to oviposition can wait until plants are susceptible, but fall-seeded plantings cannot escape root maggot oviposition and damage because some females would have already emerged and mated by the time that seedlings of a susceptible growth stage are present.

The root maggot damage levels observed in this study are similar to those observed in other agronomic studies conducted at the same sites and would have been associated with substantial yield losses. For example, Dosdall et al. (2003) found that mean seed yields decreased by ≈740 kg/ha for comparable mean root maggot damage rating levels (2.5 U).

Dosdall et al. (1996a) compared root maggot infestations and seed yields over five seeding dates beginning in early May and spaced ≈7–10 d apart. Delaying seeding until late May, rather than in early or mid-May, generally resulted in less oviposition by *Delia* spp. and significantly less root damage from larval feeding; however, seed yields for late-seeded plants tended to be lower than for plants seeded earlier. Consequently, late spring seeding of canola was not considered an appropriate cultural control practice for *Delia* spp., because plants seeded earlier seemed to take advantage of the favorable growing conditions early in the season and so could compensate for root maggot damage (Dosdall et al. 1996a). Results of the current study comparing fall versus spring seeding support earlier recommendations. Seeding canola in fall did not predispose plants to greater infestations by root maggots than seeding in spring; therefore, growers should select a seeding date based on other agronomic factors. In general, crops sown early benefit from a full season's rainfall, suffer less from weed competition, and benefit from the initial high soil nitrate levels available at the beginning of the season (Dent 2000). In an extensive study spanning several sites throughout Alberta, Clayton et al. (2004a) found that in eight of 10 site-years, seed yields of canola planted in early spring exceeded those of fall or normal spring seeding dates. They therefore recommended seeding canola as soon as possible in spring for optimal yields, a recommendation that is appropriate when considering results of the current study.

Plants of *B. rapa* were more susceptible to root maggot infestations than those of *B. napus* (experiment 1), a result consistent with Dosdall et al. (1994, 2000). Similarly, we found that root maggot damage to canola declined significantly with an increase in seeding rate for plants seeded in May (Fig. 1). Dosdall et al. (1995, 1996a) found that females of *Delia* spp. preferred to oviposit on plants with large basal stems. In dense plantings (at higher seeding rates), basal stems are smaller than when plant density is low, resulting in less root maggot oviposition and damage. However, our results that root maggot damage to canola was not significantly affected by cultivar (experiments 2 and 3), or by time of weed removal (experiment 2), are inconsistent with earlier studies (Dosdall et al. 1994, 2000, 2003). Lack of congruence in root maggot infestation data for varietal and time of weed removal effects can be explained by differences in the canola germplasm evaluated here compared with previous studies, and differences in the numbers of experiment-years of data analyzed in each study. For example, Dosdall et al. (1994, 2000) found differences in susceptibilities to root maggot attack among cultivars of *B. napus* that were different than those investigated in the current study. In addition, Dosdall et al. (2003) found that root maggot infestation levels declined with a delay in the timing of weed removal from the two- to six-leaf stages of canola development. Here, we investigated time of weed removal over only three site-years, compared with 10 in Dosdall et al. (2003), so less statistical power in the current investigation may have failed to detect a treatment effect.

We found that environmental factors could have an important effect on root maggot damage to canola, as indicated by significant interactions between site and seeding date (Table 4). For example, at Fort Saskatchewan during 1998–1999, highest root maggot damage ratings occurred to plants seeded in fall, yet at Vegreville during the same year, damage was greatest to plants seeded in April (data not shown). Averaging root maggot damage over an extensive series of sites and years, as done in the current study, determined that root maggot damage in fall-seeded canola was equivalent to, or less than, damage to spring-seeded plants. However, it is evident that biotic factors, abiotic factors, or both, can have considerable influence on root maggot infestations, resulting in greater damage to fall-seeded than spring-seeded plants in some situations.

Our experiments were conducted using relatively small plots, ranging from 12 $m^2$ (experiment 1) to 54 and 72 $m^2$ (experiment 3). Results from small plot research might not always translate well to large-scale commercial fields, because in a choice situation (i.e., small plot studies) root maggot females may more readily choose preferred canola plants for oviposition. However, in a no-choice situation (i.e., large commercial fields), the possibility exists that plants grown under agronomic conditions less favored by root maggots could still be infested to a substantial degree for a given population of *Delia* spp. adults. Further studies on a larger scale are needed to adequately address the relationship between responses of *Delia* spp. in choice and no-choice field situations.

Polymer seed coatings designed to prevent premature germination of canola in fall-seeded systems have not yet been effective for producing consistent plant densities. Clayton et al. (2004a), Johnson et al. (2004), and Dosdall and Stevenson (2005) found that even with polymer seed coatings, adequate fall-seeded canola plant stands sometimes failed to establish, apparently because unseasonably mild temperatures during winter prompted premature seedling germination and their subsequent death by frost. For fall seeding to be widely adopted by growers, technologies will need to be developed to prevent premature germination and a more thorough understanding must be gained of the factors associated with plant stand failure (Johnson et al. 2004). However, once fall seeding technologies are perfected, our results indicate that this strategy does not predispose plants to greater infestations by root maggots than seeding in spring.

The covariance analysis demonstrated the importance of increasing plant densities for reducing damage by *Delia* spp. The significant relationship associated with increasing plant density for canola seeded in May, but not on earlier dates (Fig. 1), is likely a reflection of differences in the compensatory ability of canola seeded on different dates. Canola seeded in fall or April reached the vulnerable developmental stages for oviposition and larval damage before plants seeded in May. Plants injured early in the season could likely take advantage of greater quantities of residual soil moisture and nutrients to strengthen their root systems in compensation for root maggot attack. However, plants injured later, when both moisture and nutrients are more limited, could likely compensate to a lesser degree. Growers in regions infested annually with high populations of root maggots should seed at rates selected to ensure vigorous plant stands (Dosdall et al. 1998), but this strategy is particularly important when seeding in mid-May (Fig. 1; Table 8).

The potential benefits to producers of fall dormant seeding of canola will ensure that this practice continues to receive research attention to reduce the associated risks of frost damage and inadequate plant establishment. Our research results provide additional incentive to develop improved fall seeding technologies, because the threat of economic damage from root maggots is not increased in fall-seeded systems. Our studies also indicate that the adoption of alternative seeding management systems, such as fall seeding at higher rates and with less susceptible canola species can help minimize crop damage from these pests. When coupled with agronomic practices shown previously to increase competitiveness of the crop relative to these pests, like maintaining appropriate row spacings, optimal soil fertility, and appropriate tillage regimes (Dosdall et al. 1996b, 1998, 2004), root maggot infestations and crop losses can be considerably reduced in canola.

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